GFDL Summer School [2012]

Radiation and Climate Applications

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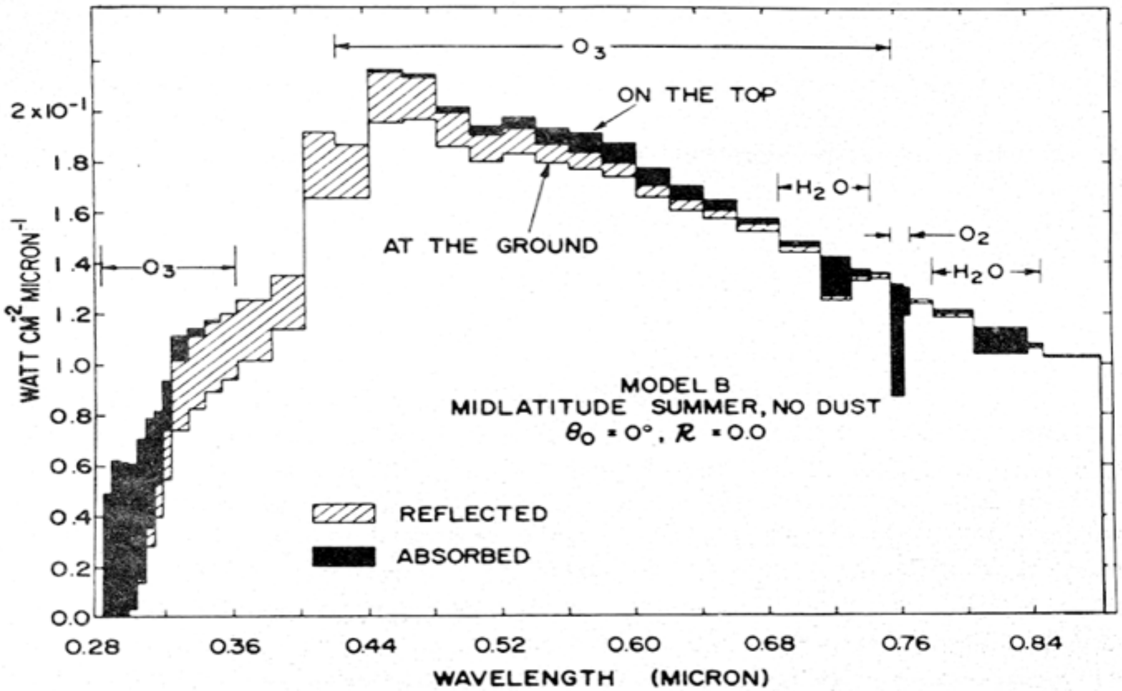
Factors involved in the Global Heat Balance

- Gradients in Temperature
- Amount and location of species (gases, aerosols and clouds)
- Radiative (absorption, emission, reflection) properties of species in the electromagnetic spectrum
- Radiative properties of the surface

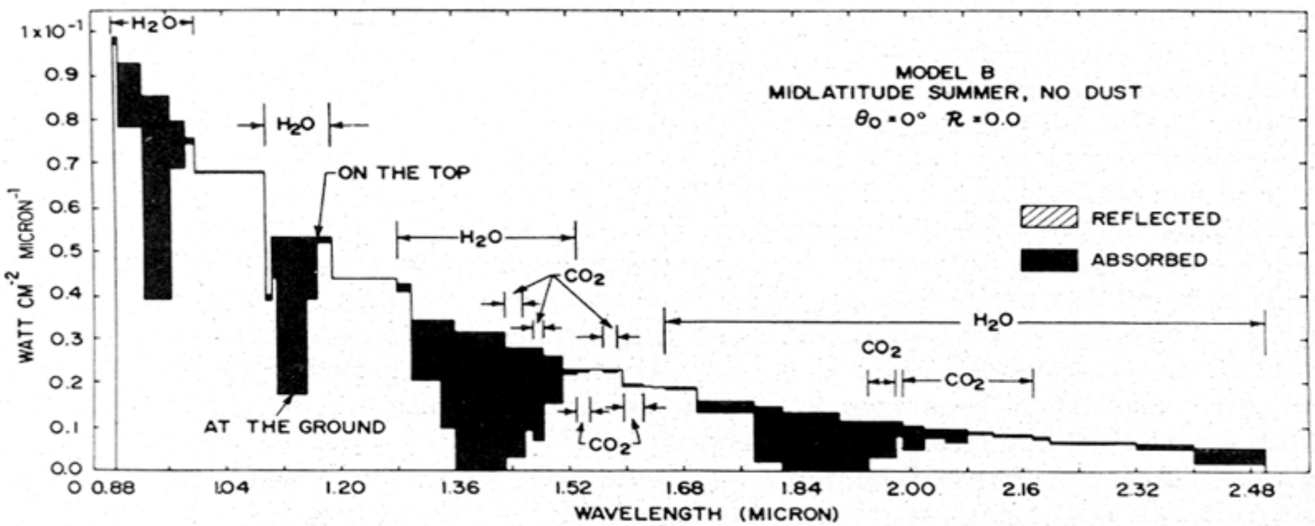
➢ Convection (arising due to differential heating of surface and atmosphere)

➢ Large-scale dynamical flows caused by planetary rotation, topography, and land-sea contrast

❑ FEEDBACKS [Water vapor, surface, clouds]

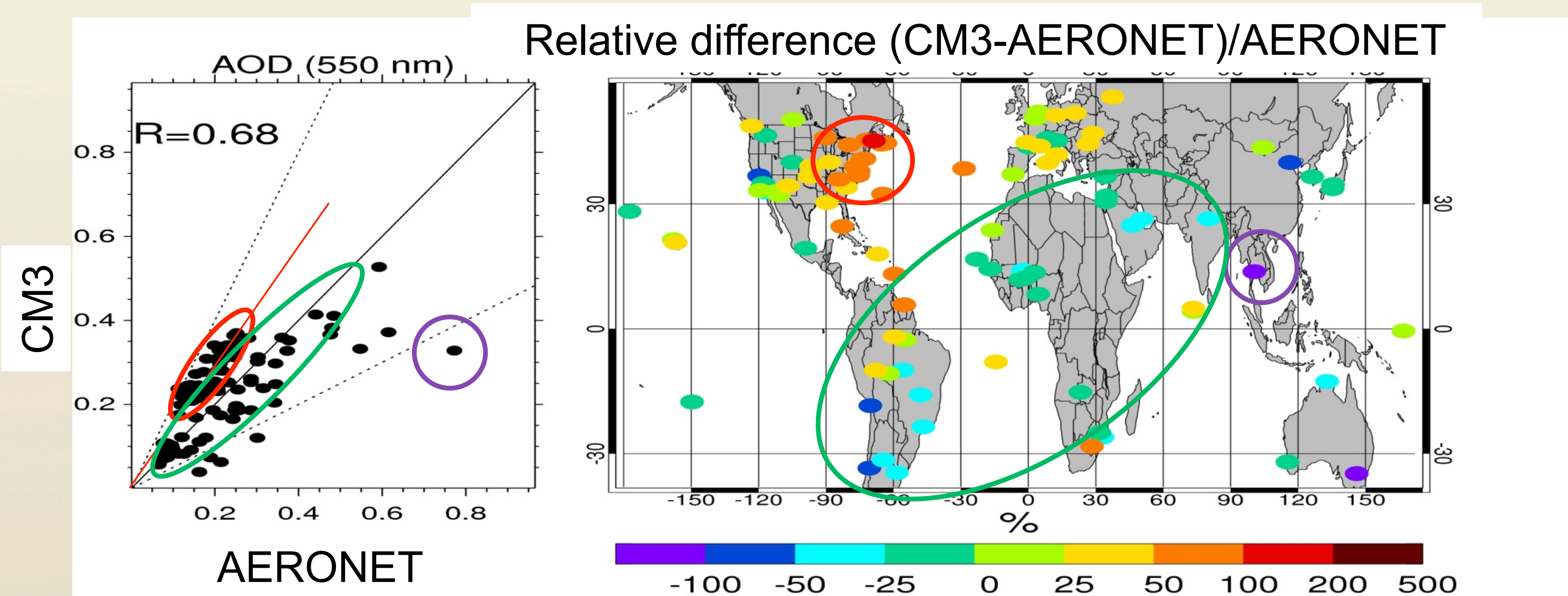

O3
ON THE TOP
AT THE GROUND
H2 O
O2
H2 O
O3
MODEL B
MIDLATITUDE SUMMER, NO DUST
θ0 = 0°, R = 0.0
REFLECTED
ABSORBED
WATT CM-2 MICRON-1
WAVELENGTH (MICRON)

VIS


H2O
MODEL B
MIDLATITUDE SUMMER, NO DUST
θ0 = 0° R = 0.0
H2O
ON THE TOP
H2O
CO2
REFLECTED
ABSORBED
H2O
CO2
CO2
AT THE GROUND
CO2
WATT CM-2 MICRON-1
WAVELENGTH (MICRON)

Near-IR

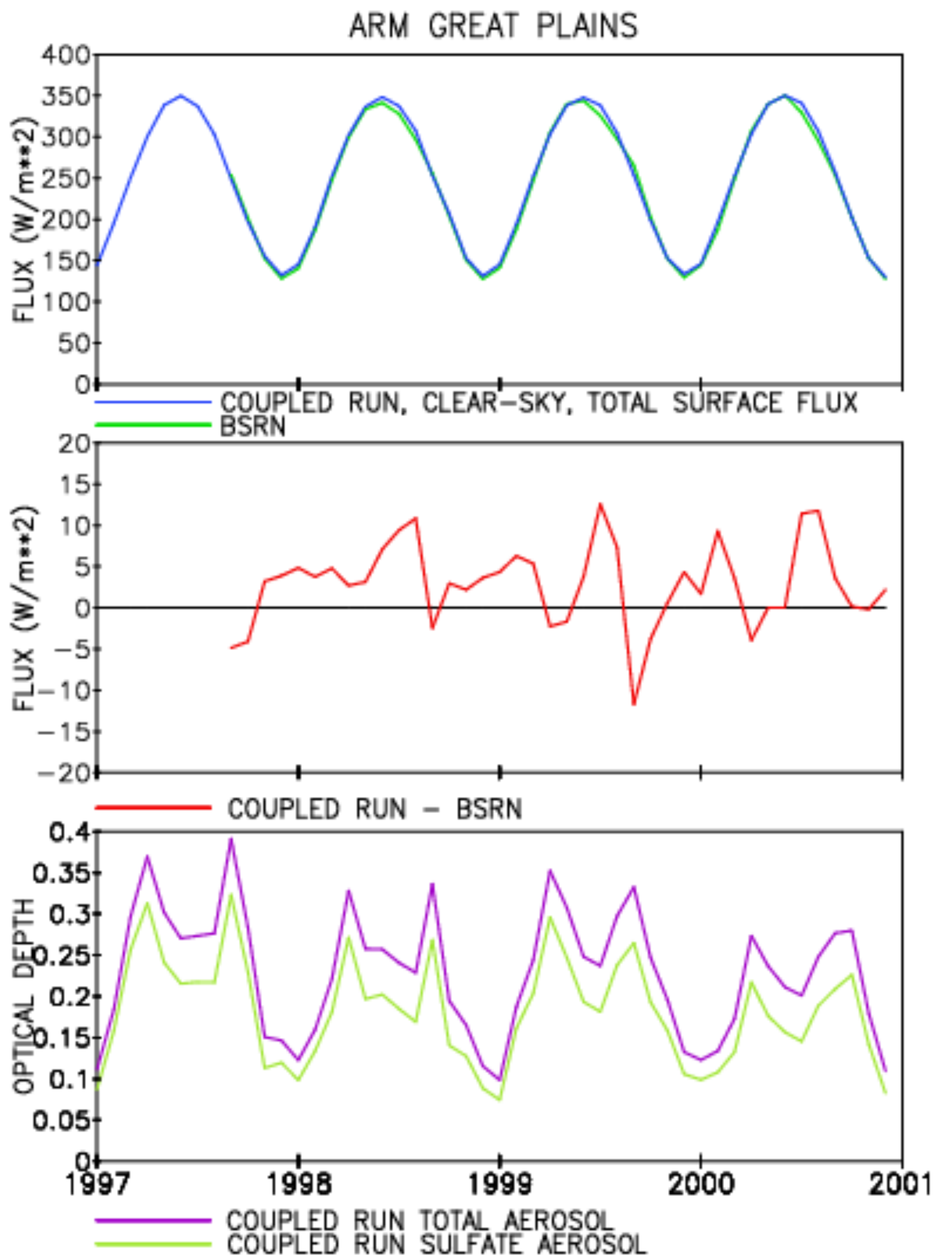
Comparison CM3 AOD with sunphotometers



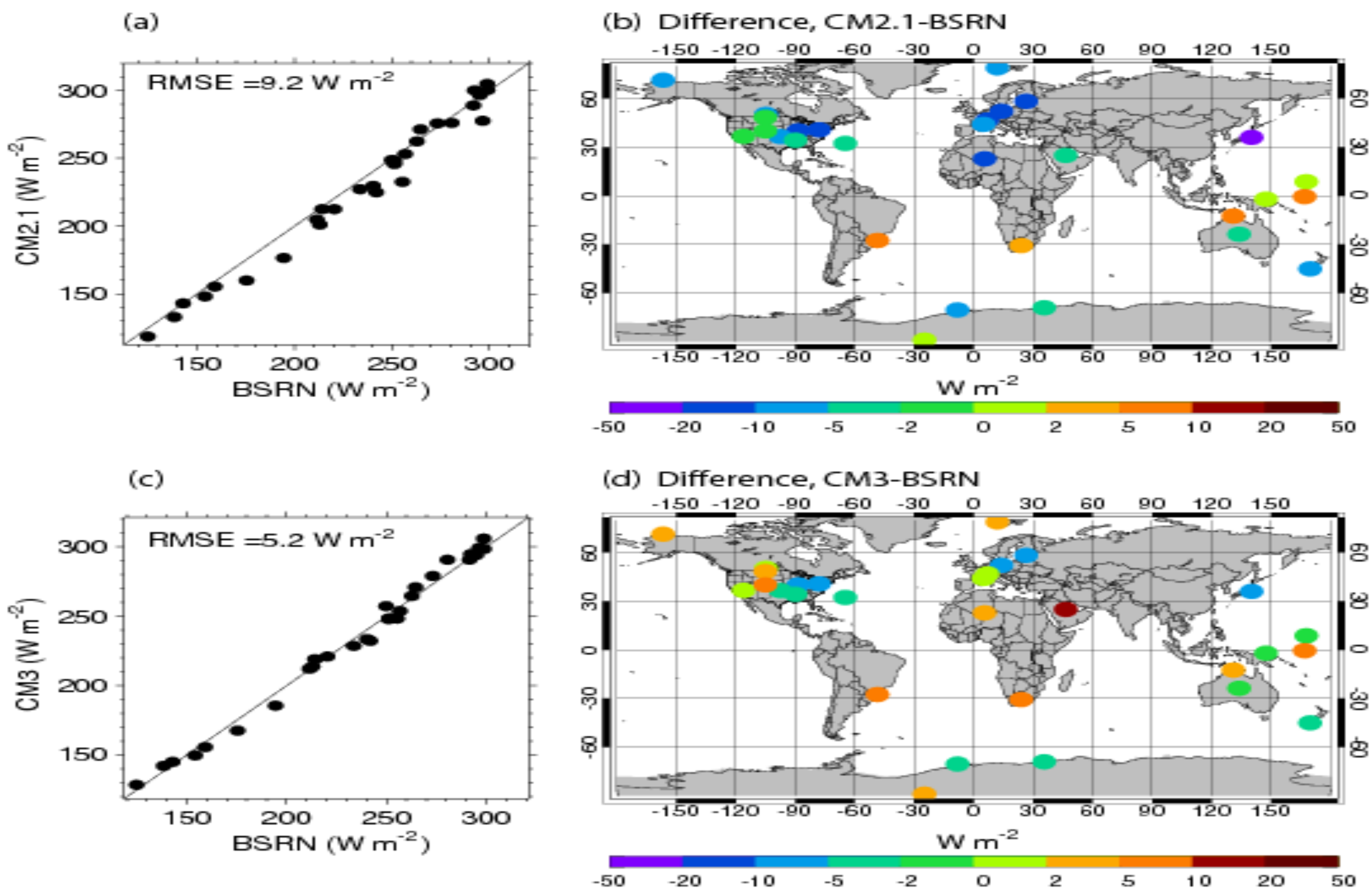
CM3 < 1.5 AERONET in US East coast

CM3 ~ AERONET in biomass burning, dusty regions, India

CM3 < 2 over Mega-cities (e.g. Bangkok)

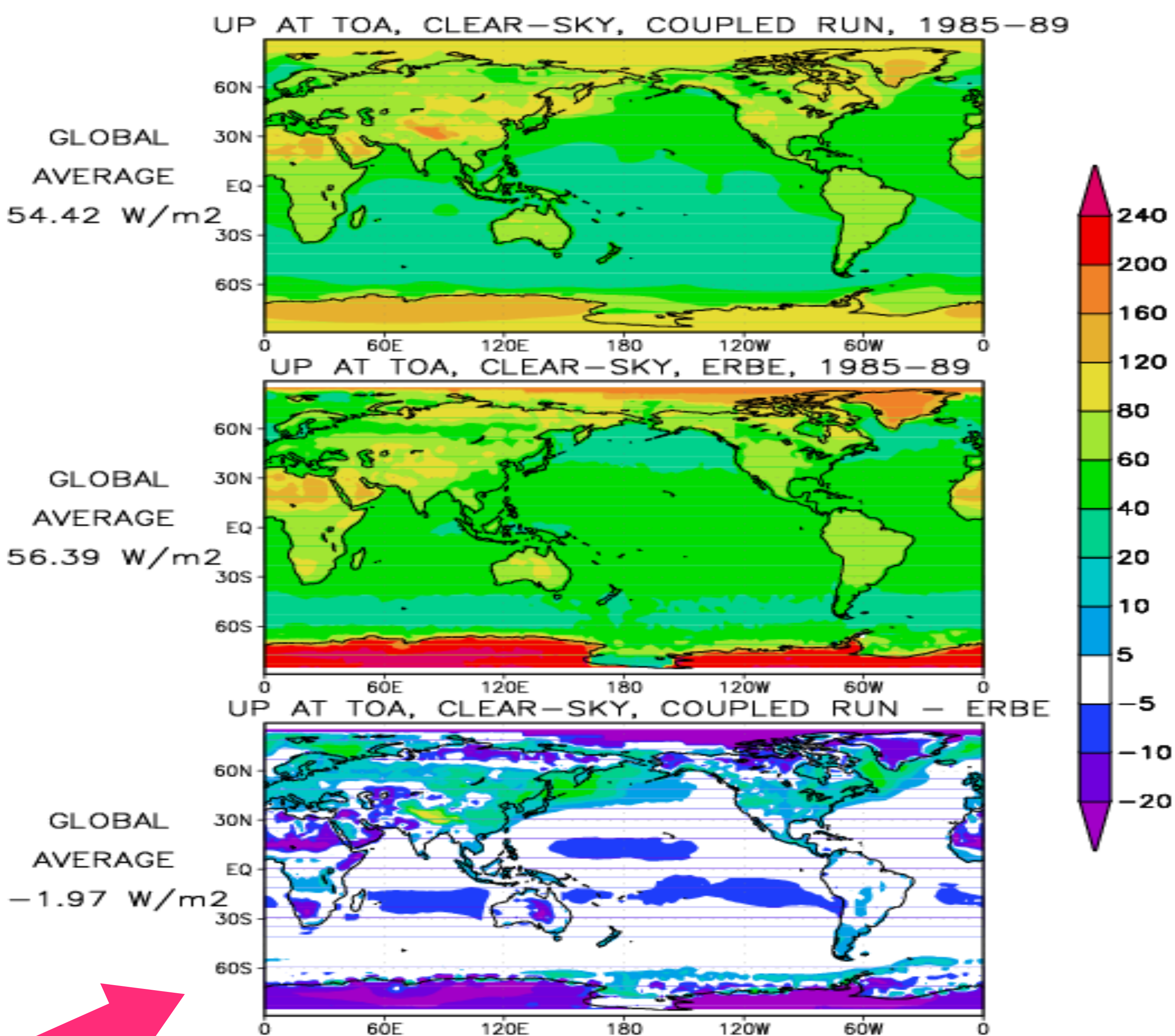

ARM GREAT PLAINS
FLUX (W/m**2)
COUPLED RUN, CLEAR-SKY, TOTAL SURFACE FLUX
BSRN
FLUX (W/m**2)
COUPLED RUN - BSRN
OPTICAL DEPTH
1997
1998
1999
2000
2001
COUPLED RUN TOTAL AEROSOL
COUPLED RUN SULFATE AEROSOL

Surface Clear-Sky Downward Shortwave Radiation



from Donner *et al.* (2011, *J. Climate*)

Comparison of Clear-Sky SW @ TOA



Term "RADIATIVE FORCING OF CLIMATE CHANGE" ===>

changes in the radiation balance of the surface-atmosphere system imposed by external factors

- *with no changes in stratospheric dynamics;*
- *with no surface feedbacks in operation;*
- *no changes in tropospheric motions or its thermodynamic state;*
- *no dynamically-induced changes in the amount and distribution of atmospheric water.*

"Global-mean" refers to globally-and-annually-averaged estimate.

FORCING - RESPONSE RELATION

$$\Delta T_s = \lambda * (\Delta F)$$

T_s = global-mean, annual-mean surface temperature

ΔF = global-mean, annual-mean radiative forcing evaluated at tropopause after equilibration of stratosphere

λ = global-mean climate sensitivity factor (parameter)

relates to feedbacks in the climate system

$\Delta F|_{2\times CO_2} \cong 4 \frac{W}{m^2}$

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PRINCETON, NJ 08542
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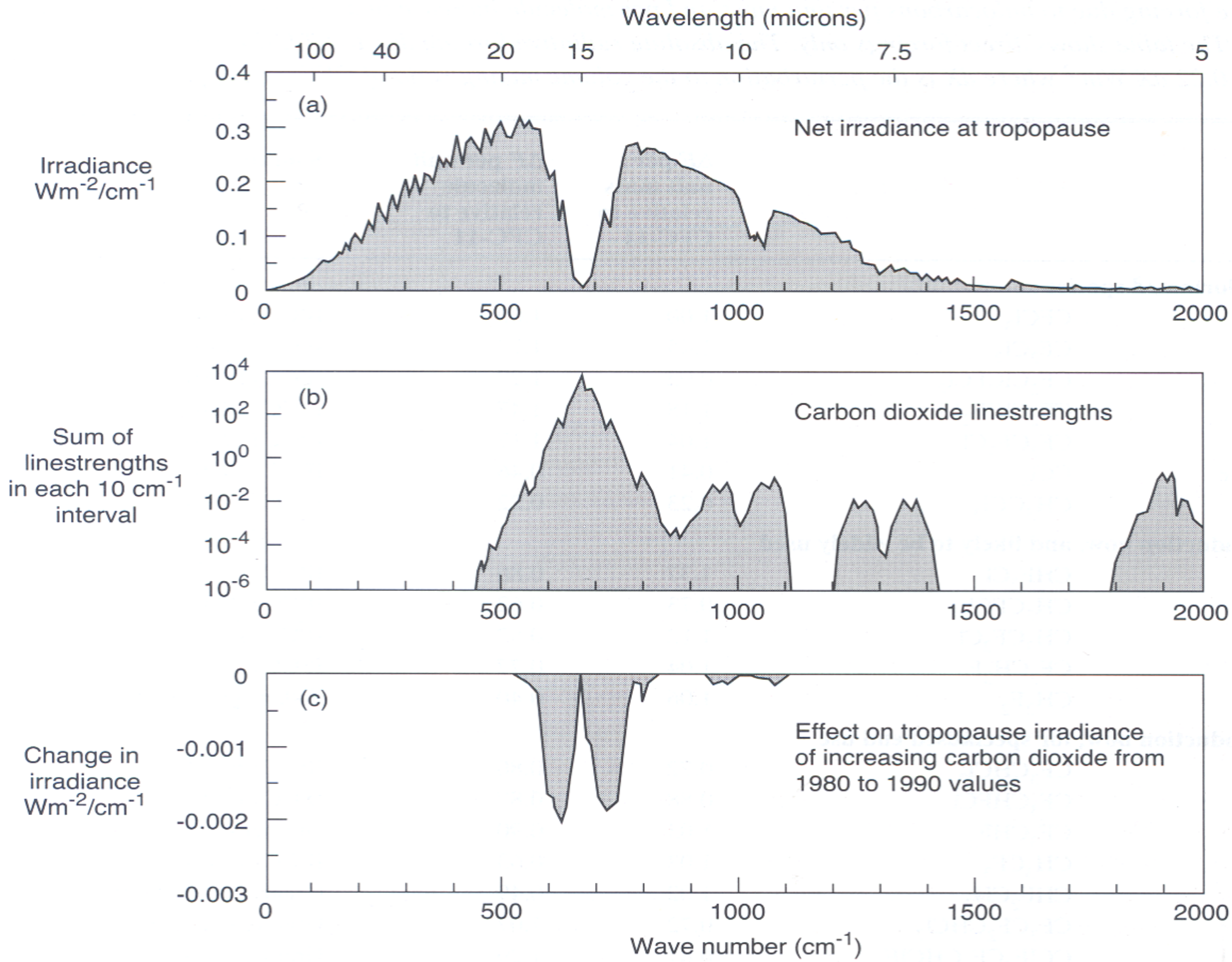
$\Delta T_s \sim 1.9 - 5\ K$



IPCC (1994)

Forcing goes roughly as the logarithm of the increase in CO2.
For methane, the forcing goes as the square root of the increase.
For halocarbons, the forcing goes linear in concentration change.

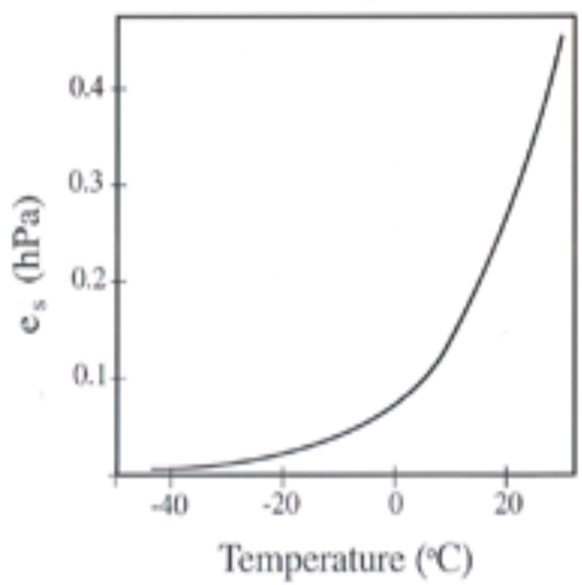
Clausius-Clapeyron equation

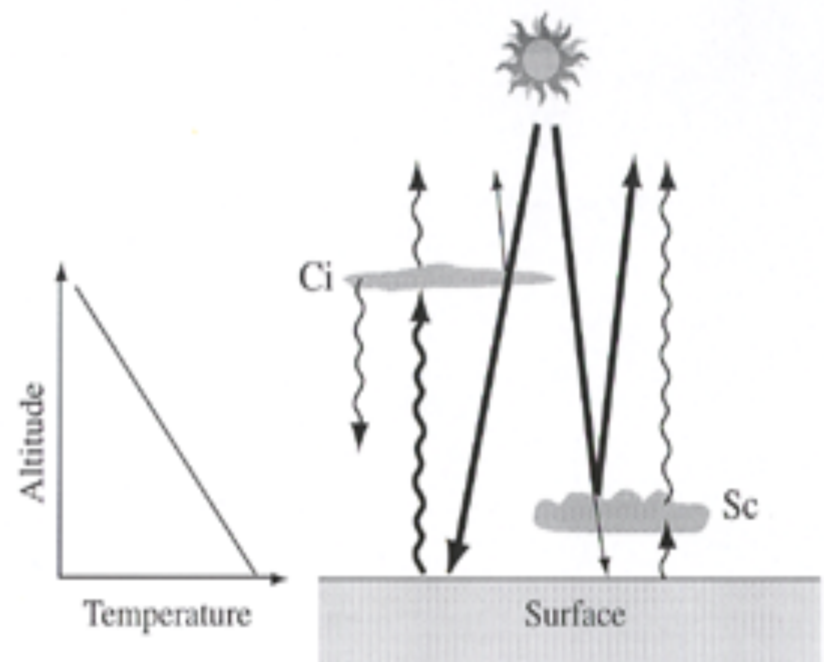
Saturation vapor pressure e_s:

$$e_s(T) = e_s(T_1)\exp\left[-\frac{L_v}{R_v}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)\right]$$

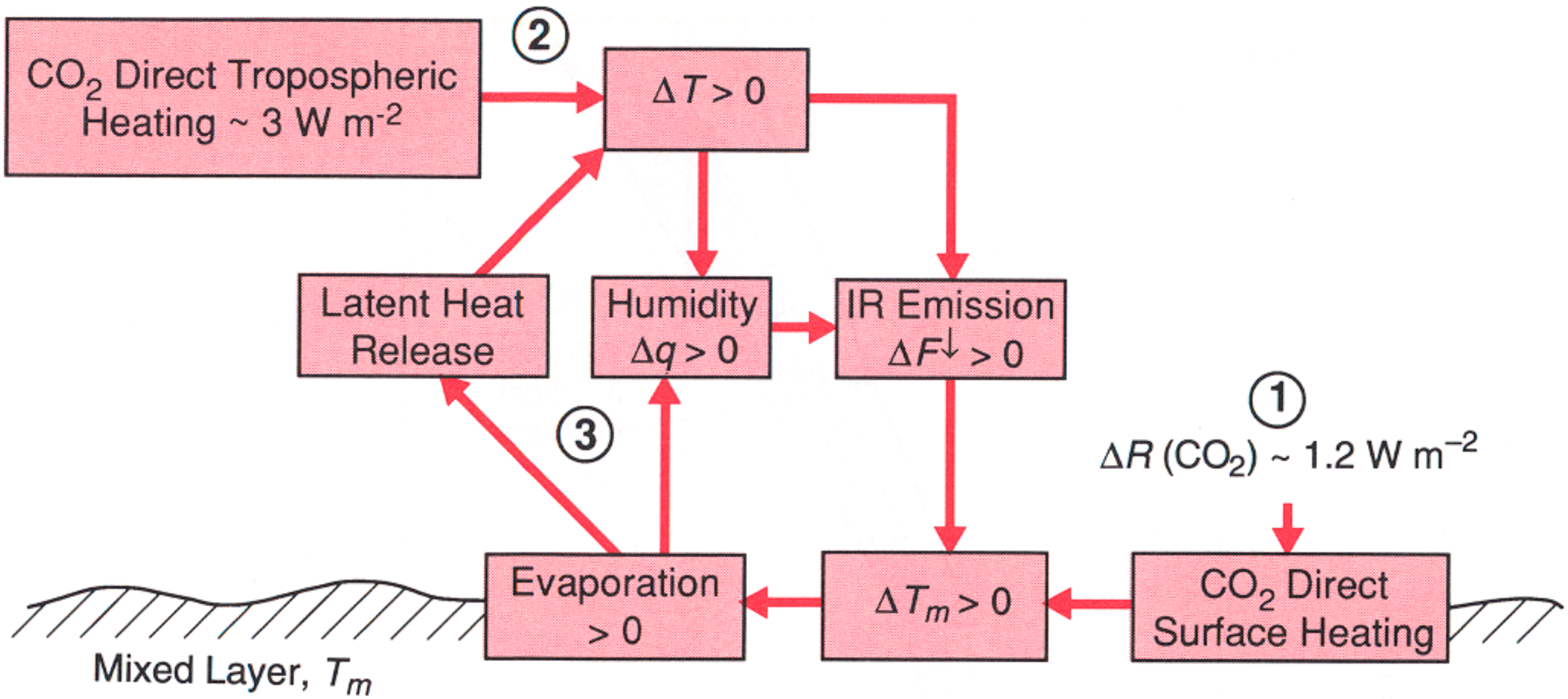
L_v is latent heat of water evaporation

R_v is gas constant for water vapor





Ci is cirrus
Sc is stratocumulus

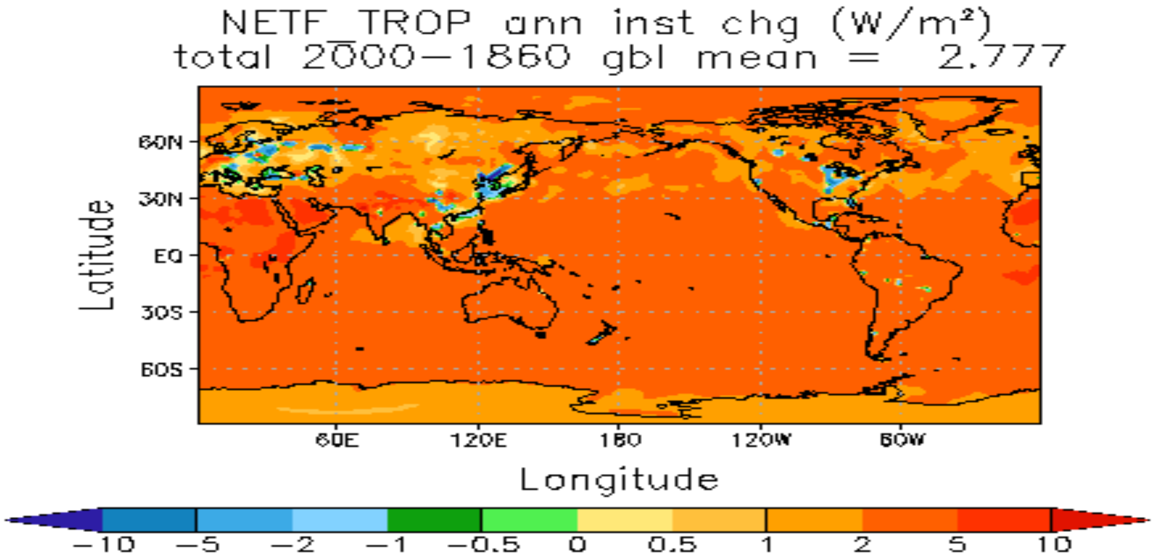


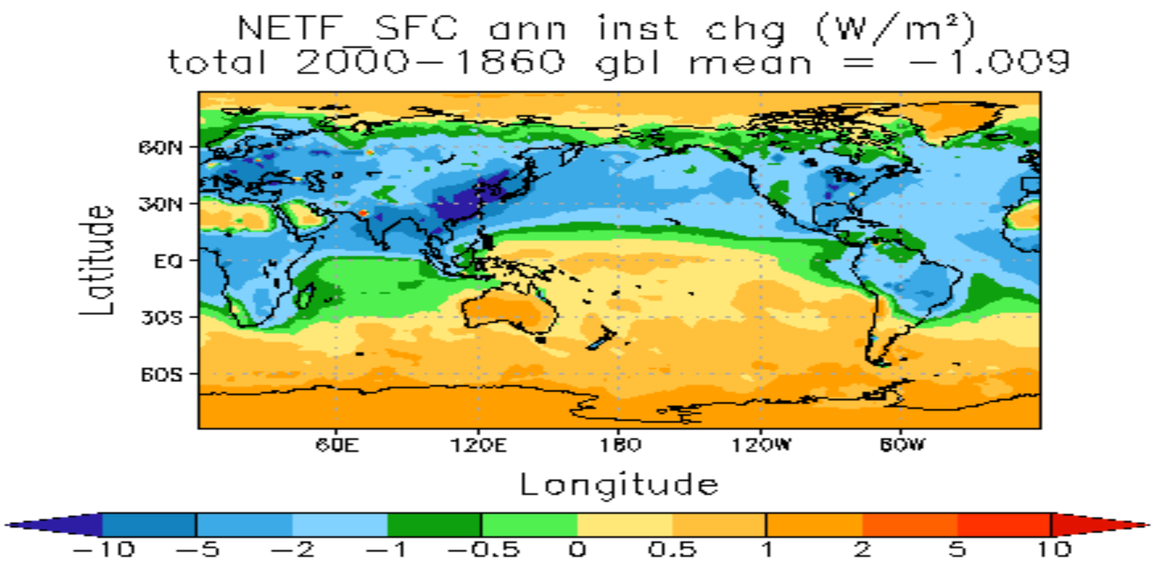
Numbers correspond to doubling of CO_2

	Process (1)	Process (2)	Process (3)	Total
Flux (W m^{-2})	1.2	2.3	12.0	15.5
Percent	8.0	15.0	77.0	
ΔT_s (model dependent)	0.17	0.33	1.7	2.2

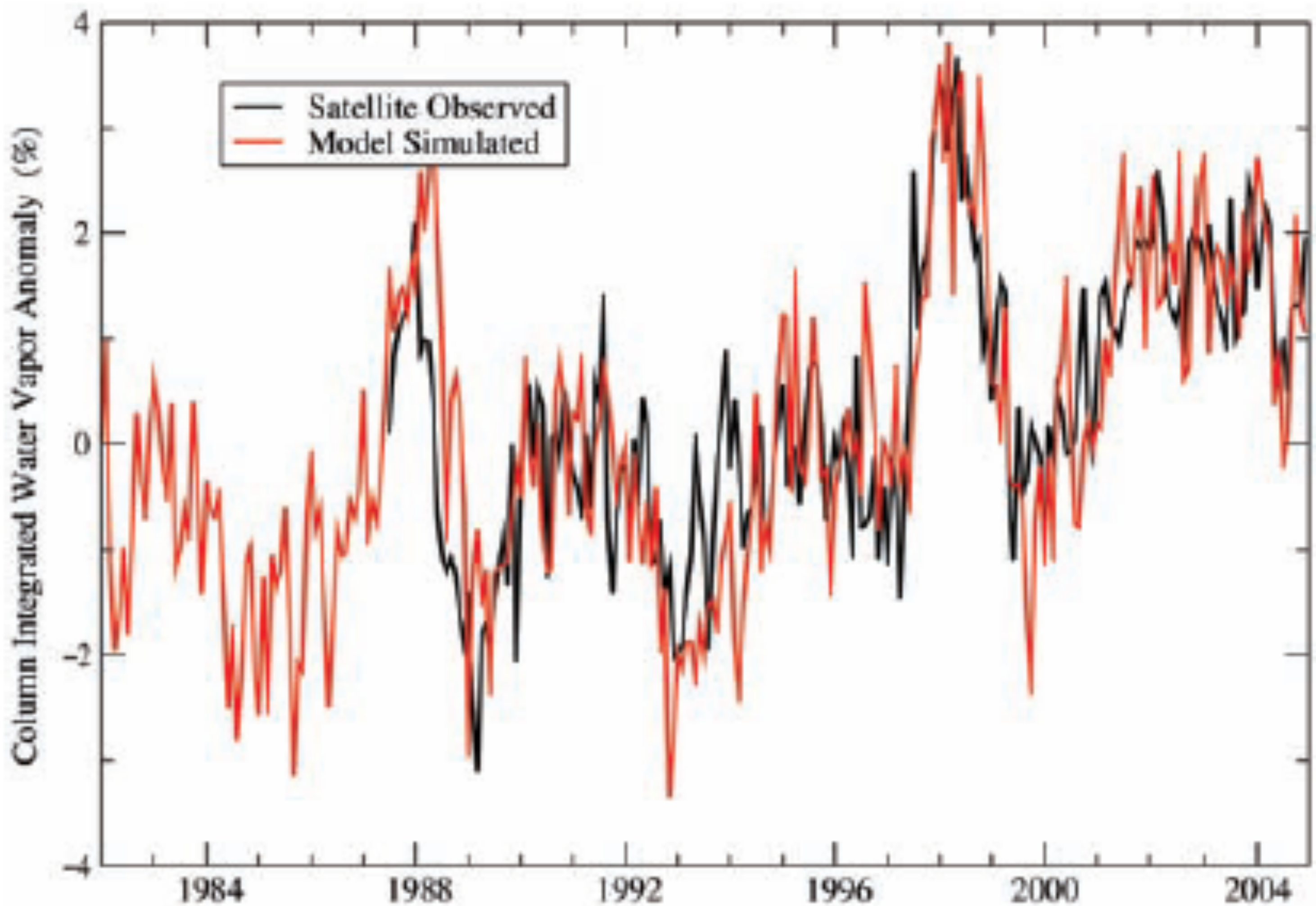
Ramanathan (*J. Atmos. Sci.*, 1981)

Forcing (preindustrial to present)





Soden et al. [*Science*, 2005]

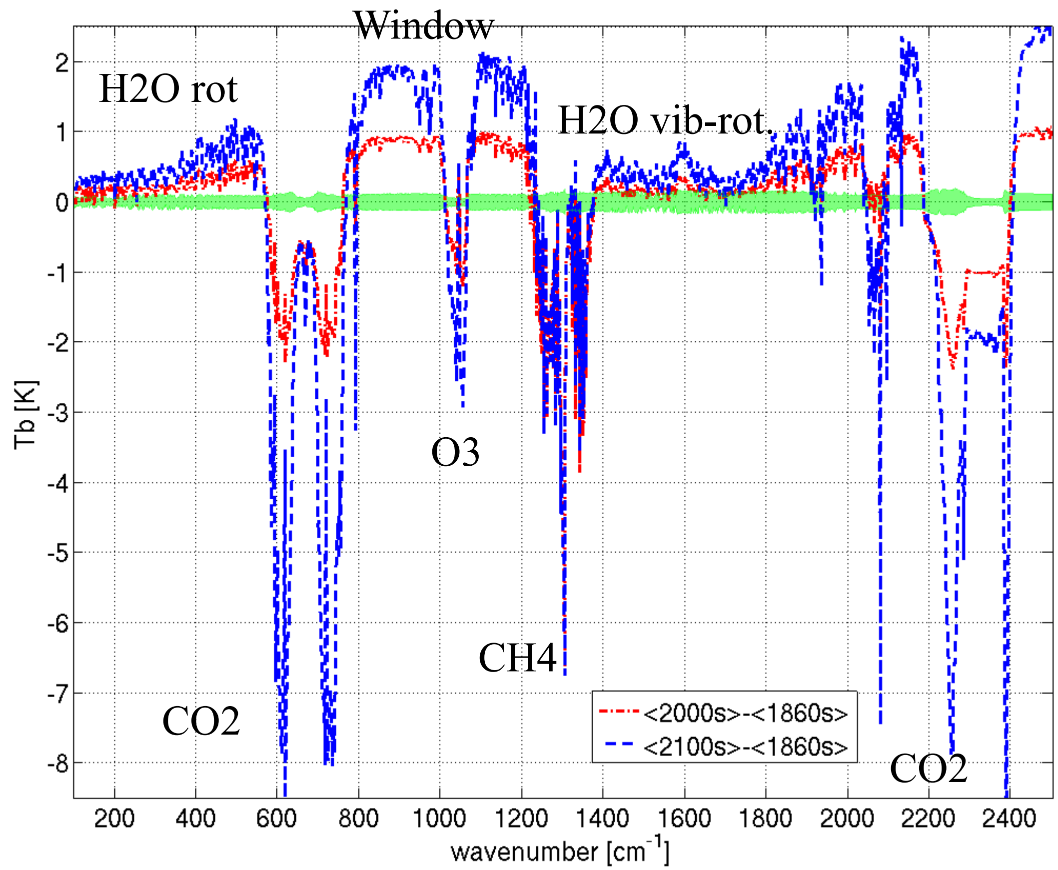


Difference in Brightness Temperatures: 1860s to 2000s, and1860s to 2100s [Huang and Ramaswamy, 2009]

Climate Sensitivity

- – **Red**: <2000-2004> minus <1861-1865>
- – **Blue**: <2100-2104> minus <1861-1865>
- – **Green**: unforced natural variability

- **Results:**
  - – window regions – surface warming;
  - – CO2 bands – stratospheric cooling; rise in tropos. emission level (also O3 and CH4 bands);
  - – H2O bands – atmospheric warming is compensated by water vapor feedbacks.



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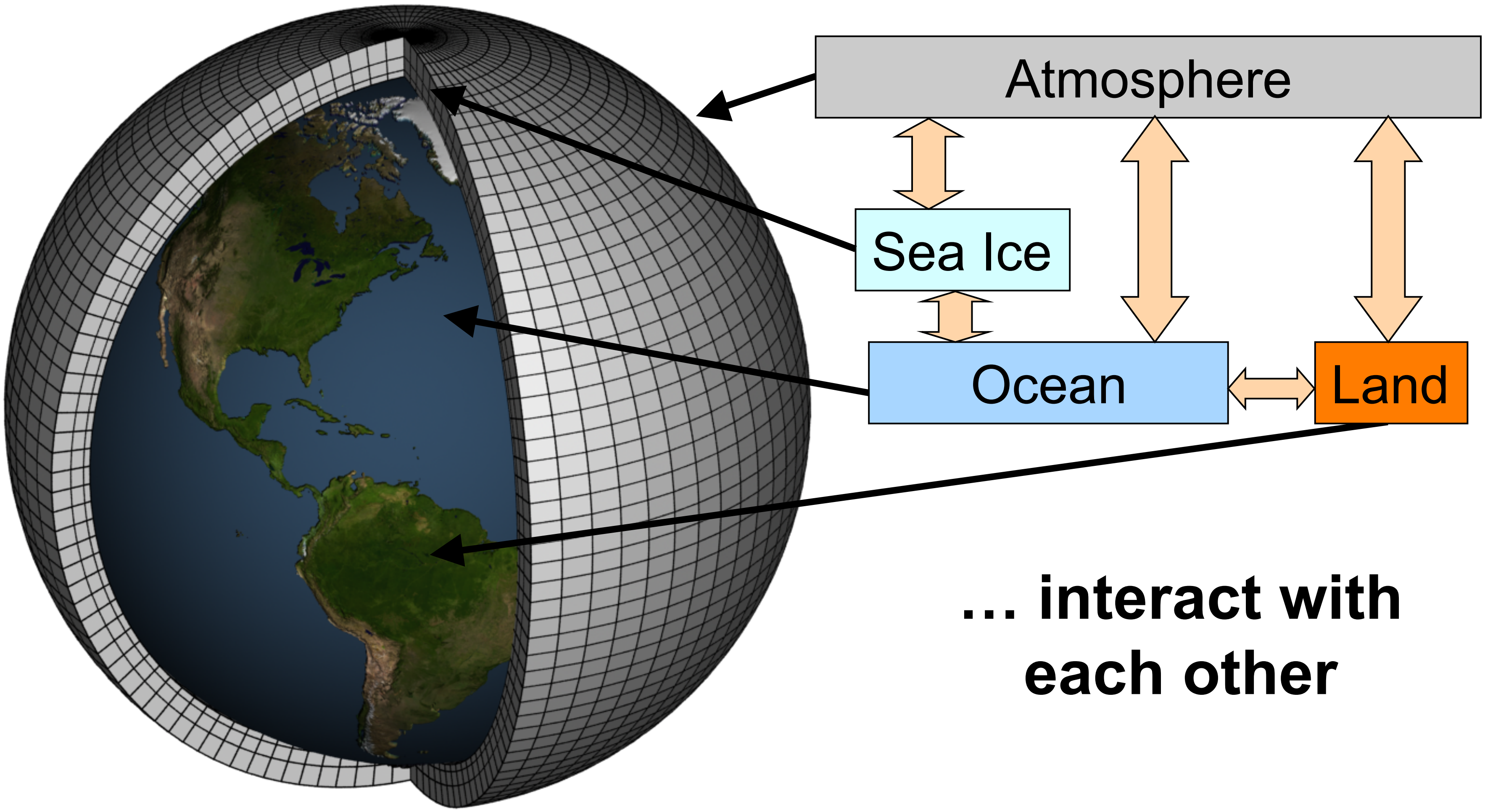
The END

The Components of Global Climate…



… interact with each other

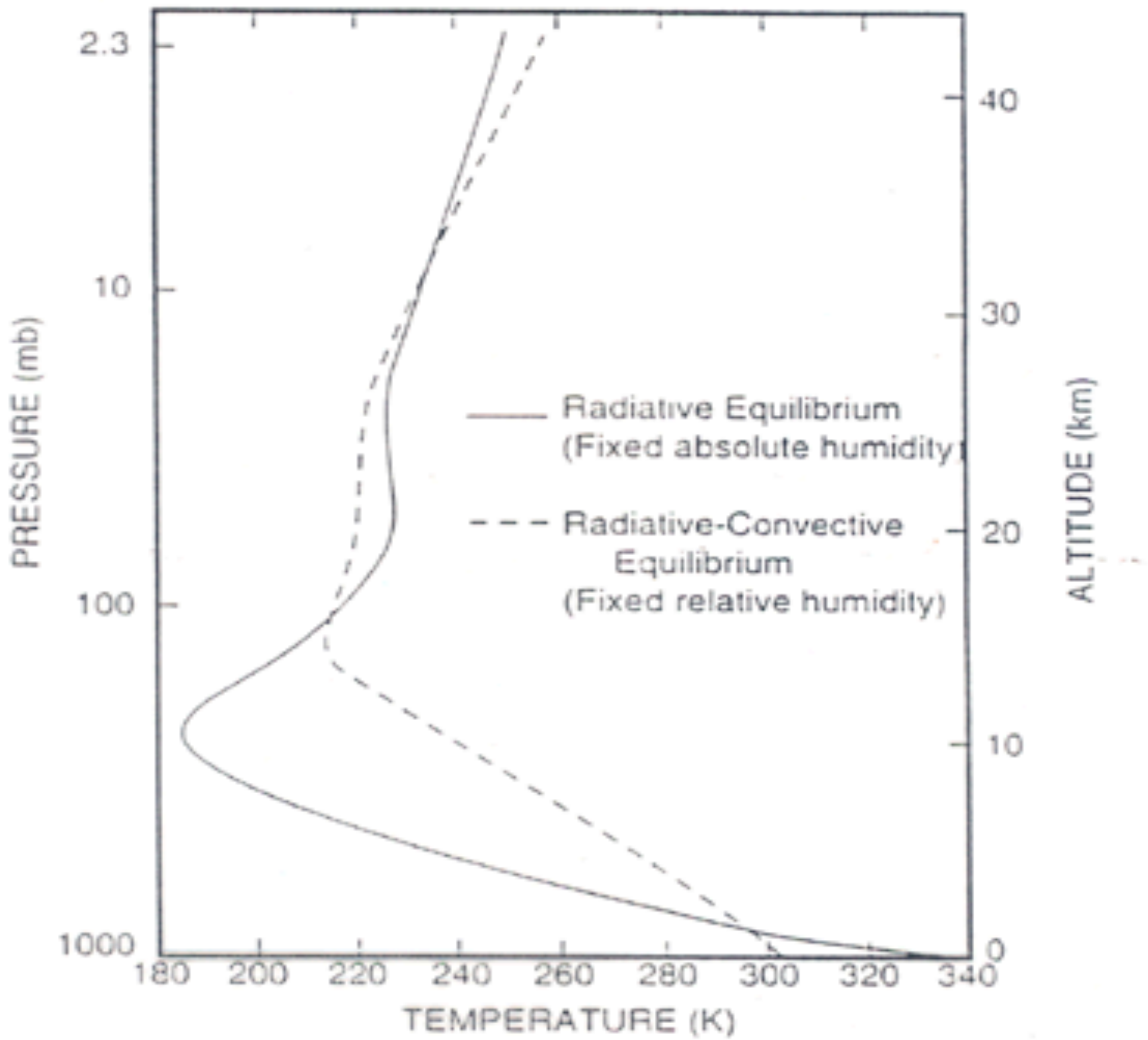
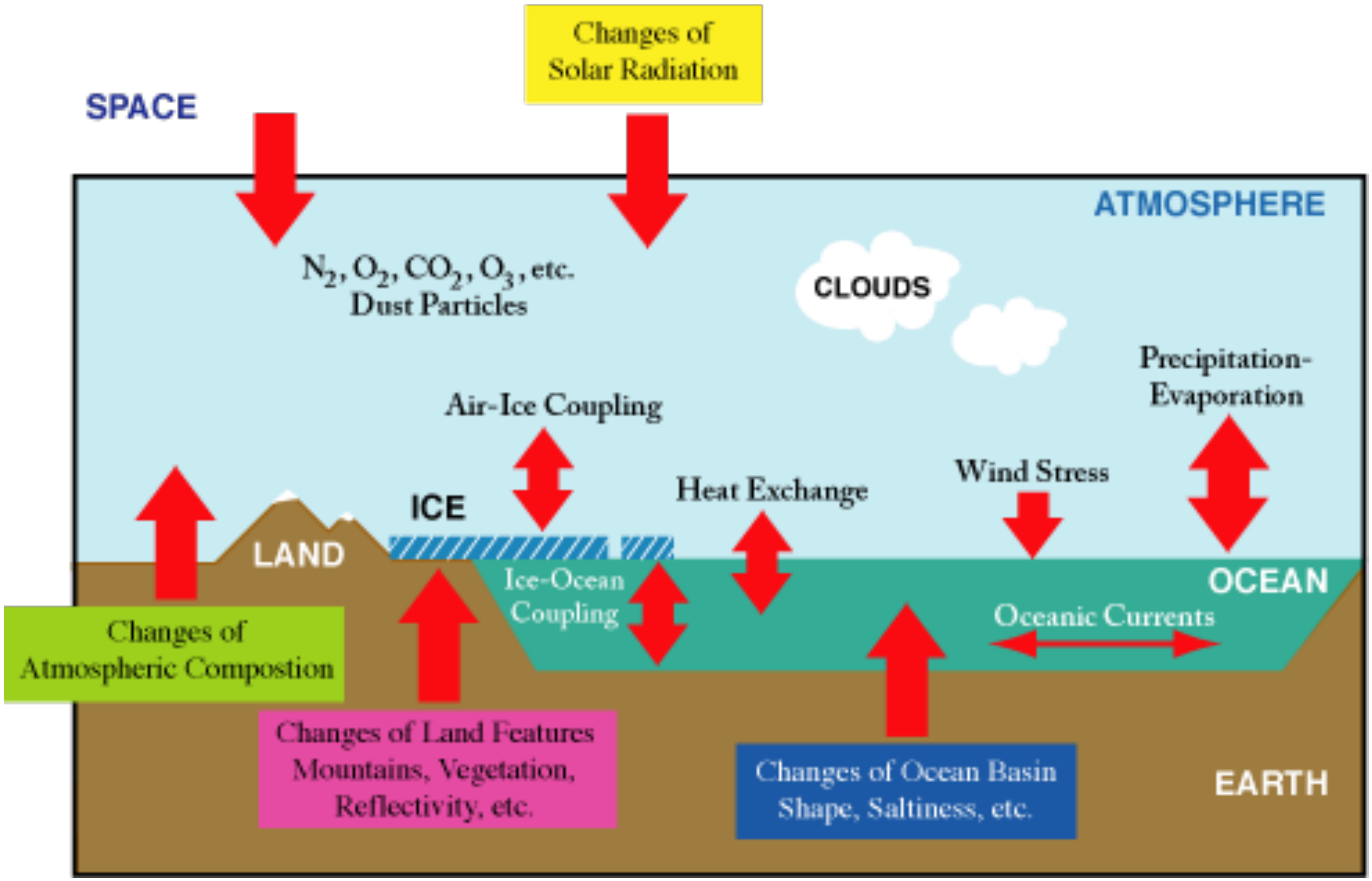


Figure 8.23 Temperature under radiative equilibrium (solid line) and radiative–convective equilibrium (dashed line) from calculations that include mean distributions of water vapor, carbon dioxide, and ozone. Adapted from Manabe and Wetherald (1967).

Components of the Coupled Atmosphere-Ocean-Ice Earth Climate System



Molecule	Spectral Range cm^{-1}	Band Strength $cm^{-2} atm^{-1}$ at 296K
CO_2	550-800	220
O_3	950-1200	312
N_2O	1200-1350	218
CH_4	950-1650	134
$CFCl_3$ (CFC11)	800-900	1828
CF_2Cl_2 (CFC12)	875-950	1446
CF_3Cl (CFC13)	1075-1125	1758

Total Outgoing LW radiation ~ 240 W/m^2

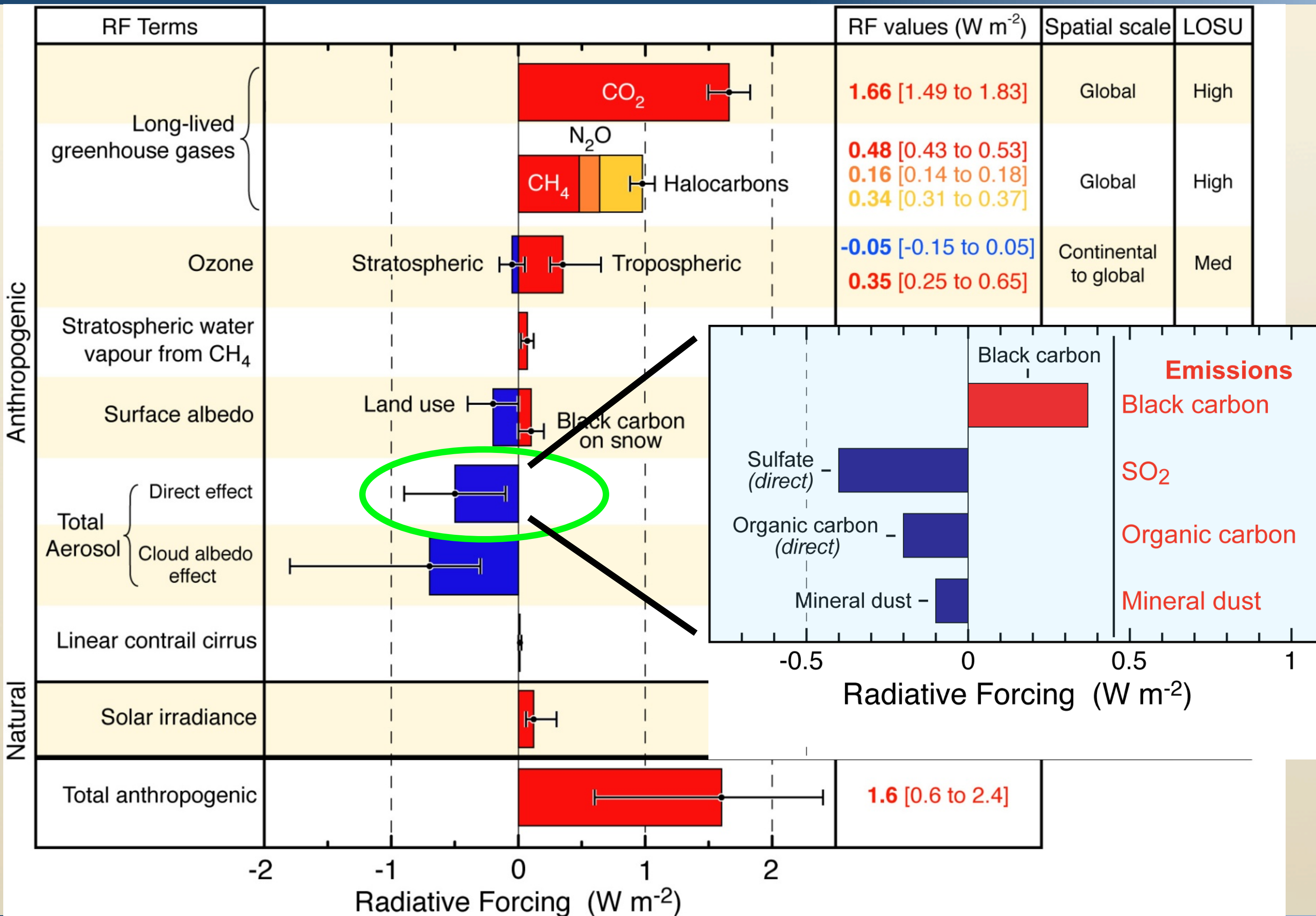
1.3 Trapping of terrestrial radiation by current trace gases. The results are estimated from model computations and pertain to global-annual average conditions.

Gas	ΔF^* (W m^{-2})	Reference
H_2O	55	Ramanathan & Coakley (1978)
CO_2	20	" "
Ozone (Troposphere)	1.5	Fishman et al. (1979)
Ozone (Stratosphere)	5	Ramanathan & Dickinson (1979)
CH_4	1.7	Donner & Ramanathan (1980)
N_2O	1.4	" "

* ΔF is the reduction in the thermal radiation emitted to space by the surface-atmosphere system.

Radiative Forcing Components in 2005

(since preindustrial times, ca. 1750)



IPCC, AR4, 2007 www.ipcc.ch

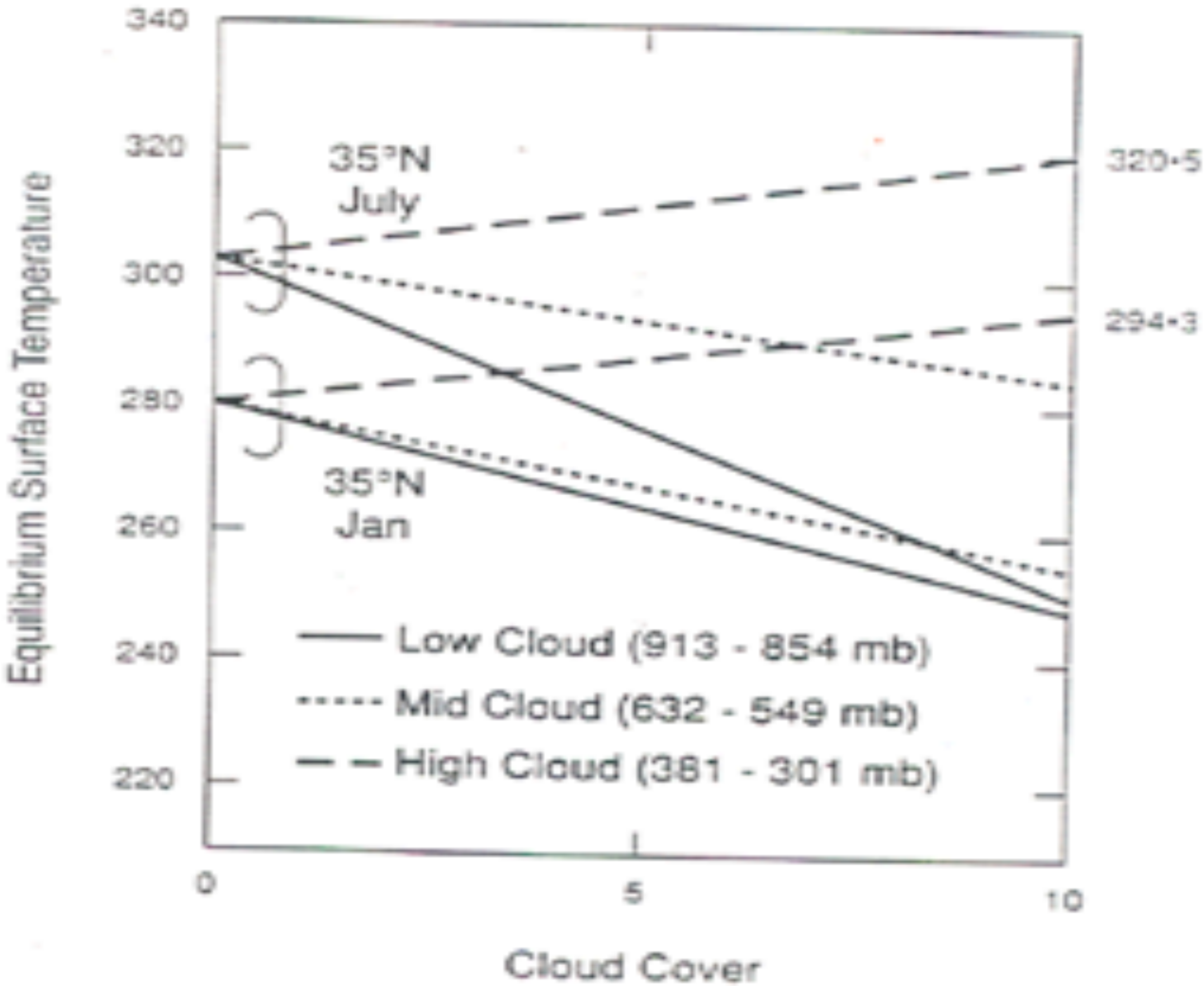


Fig. 10.7 Surface temperature obtained from a one-dimensional radiative-convective model versus fractional cloud cover. Results are shown for low, mid-level and high cloud cover. From Stephens and Webster (1981).